Development of a Vertically Profiling, High-Resolution, Digital Zooplankton Imaging System

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LONG-TERM GOALS

The scientific goal of this project is to develop an improved capability for mapping the fine-scale horizontal and vertical distributions of mesozooplankton and other comparably sized particles in the oceans. Mapping of organisms in relation to environmental factors will help to understand the processes that lead to fine-scale patchiness. In-order to collect such biological and physical data, we require a system capable of quantifying zooplankton distributions and abundances on appropriate scales. A central component of this project is to develop a profiling instrument capable of collecting high-resolution images of zooplankton and other particles in the water column and concurrent environmental data on comparable spatial and temporal scales.

OBJECTIVES

1) To interface a high-resolution digital still camera, structured light source and environmental sensors with a surface control and acquisition computer;
2) To develop a graphical software interface to control the instrument; and
3) To evaluate the size distribution and abundance data generated by the profiling instrument in relation to a conventional multi-net system.

APPROACH

The philosophy that guided the design of ZOOVIS was that there is a need for a profiling instrument capable of imaging a relatively large volume of water with sufficient resolution that the contents of each image could be classified into acoustical sound-scattering classes. Images needed to be acquired at rates that were rapid enough to produce fine-scale vertical profiles of the distributions of mesozooplankton and other comparably sized particles. A structured light sheet was necessary so that the depth of field and thickness of the light sheet could be matched in order to avoid illuminating and imaging particles beyond the depth of field of the camera (out of focus targets).

The system called ZOOVIS (zooplankton visualization system) utilizes a 2048 x 2048 pixel 14 bit monochrome digital camera combined with a collimated strobe illumination source and environmental sensors (CTD plus a transmissometer and fluorometer). These underwater components are mounted on an aluminum weldment that is connected to the surface via an electro-optical cable spooled on a winch. The cable carries power to the underwater components and links the underwater components with a surface control and acquisition computer via an Ethernet network. Images acquired by the camera are passed from an underwater computer to a surface acquisition computer, where an image-processing program examines each image for regions of interest, which are located and measured automatically.

The camera on ZOOVIS is aimed down into a horizontal stobed light sheet and images the contents of an illuminated volume. Each image is acquired by an underwater single-board computer equipped with a single PCI slot that holds the camera's acquisition card. Environmental data (conductivity, temperature, pressure, optical transmittance and fluorescence) are measured with a Sea-Bird SBE19 CTD. CTD data are acquired by the underwater PC via a serial port. The underwater PC is networked to a surface PC via Ethernet that runs through single-mode optical fiber via an electro-optical oceanographic cable. Camera images and CTD data are multiplexed and transmitted through one optical fiber while 220VAC power for the underwater system components is provided via conductors.

Custom image processing software built with Visual C++ around the Matrox Imaging Libraries allows us to examine each image for regions of interest (ROIs). ROIS meeting user-defined criteria for size and brightness are located, measured and their coordinates within each image are recorded. This can be done interactively with single images or semi-automatically in batch mode.

WORK COMPLETED

An operational instrument has been constructed and deployed successfully as part of an ONR-funded investigation of the evolution of sound-scattering layers in the vicinity of the Sill in Knight Inlet, BC. The first generation version of ZOOVIS (Fig. 1) consisted of a camera, strobe, power supply and telemetry system, and a CTD linked to a surface control and acquisition PC via an electro-optical cable and winch.

Initial assembly and testing was conducted in a lab at LSU. These tests were designed to quantify the system resolution, depth of field and image volume under various combinations of focal length, aperture and target distance. Imaging of live zooplankton in tanks was conducted to evaluate the performance of the system using realistic targets. Initial data indicated that the system met performance expectations. ZOOVIS was capable of imaging the contents of a large volume of water (hundreds of ml) at distances of 30-70 cm from the camera. Greater separation between the camera and target volume was feasible but not tested. Zooplankton with a variety of opacities (opaque to almost completely transparent) and ranging in size from 2-30 mm were clearly visible in our test images.

Field testing of ZOOVIS was conducted in collaboration with Dr. David Mackas (Institute of Ocean Sciences, Canada) and Dr. Mark Trevorrow (Defense Research Establishment, Atlantic, Canada) in an

ONR-funded project designed to investigate the acoustic patterns that develop in Knight Inlet, a coastal fjord. ZOOVIS was deployed from the CCGS Vector during cruise 2001-39 to Knight Inlet, British Columbia, Canada in November 2001. The objective of this cruise was to gain a better understanding of the physical and biological processes that contribute to elevated levels of acoustic scattering within the fjord during tidal flow. During this cruise, ZOOVIS was tested in two configurations: horizontal and downward imaging.

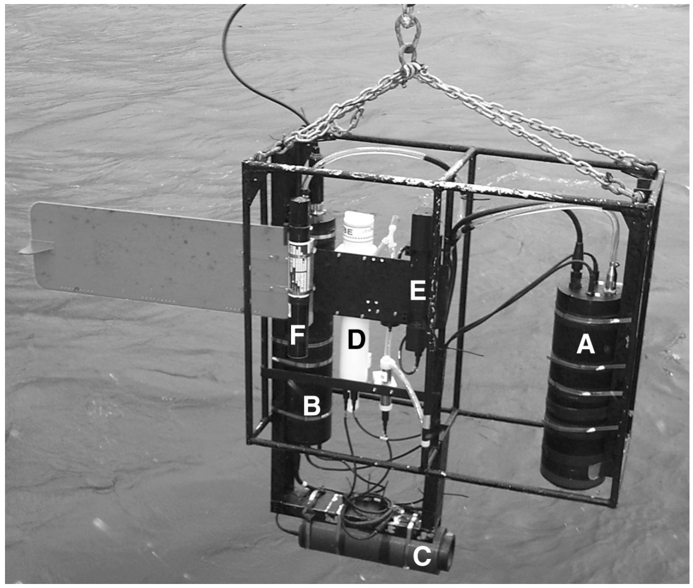

Figure 1. The prototype underwater components of ZOOVIS prior to deployment in the waters of British Columbia, Canada. A: camera housing; B: power/telemetry housing; C: strobe; D: CTD; E: transmissometer; F acoustic transponder/responder. The fluorometer is not visible in this image but is located on the opposite side of the transmissometer.

A series of optical casts were collected during concurrent acoustic surveys. One cast recorded shortly after midday (Fig. 2) provides an example of ZOOVIS data and its application to interpretation of echograms and zooplankton ecology. The instrument was deployed from the stern and a pair of profiles were collected between the surface and 166m (Fig. 2). The image volume was 443 ml (10.95 cm x 10.95 cm x 3.69 cm) and images were recorded at 0.25 Hz while ZOOVIS was lowered at approximately 50 cm s^{-1}. Following the profiles, the vessel began to steam into the current at 0.5 – 1.0 knots and a series of towyos were performed at mid-depth with vertical velocities ranging from 17.4-57.5 cm s^{-1}. Image acquisition was suspended at 142 m and ZOOVIS was recovered (Fig. 2).

RESULTS

At the field of view selected for most Knight Inlet operations (10.95 x 10.95 cm x 3.3 cm), ZOOVIS provided clear images (Fig. 3) of particles larger than 2 mm length from a distance of approximately 40 cm. Smaller targets were also imaged, however, anatomical details of small targets such as copepod antennae were not always visible. Sufficient resolution of sub-2mm targets was usually available to determine their shape and likely identity (e.g. copepods, phytoplankton colony, marine snow).

Most larger targets were detected in a region of elevated acoustical scattering located between approximately 60-120 m (Fig. 2) and these were primarily small euphausiids (<10 mm long) believed to be *Euphausia pacifica* (Fig. 3). No euphausiids were detected outside the subsurface region of elevated scattering. Images of euphausiids were clear and provided unambiguous information from which to estimate their probably taxonomy, size and orientation. Based on the volume of water imaged between 60 and 120 m (132.9 L), the density of small euphausiids within the layer was 52.7 m^{-3}.

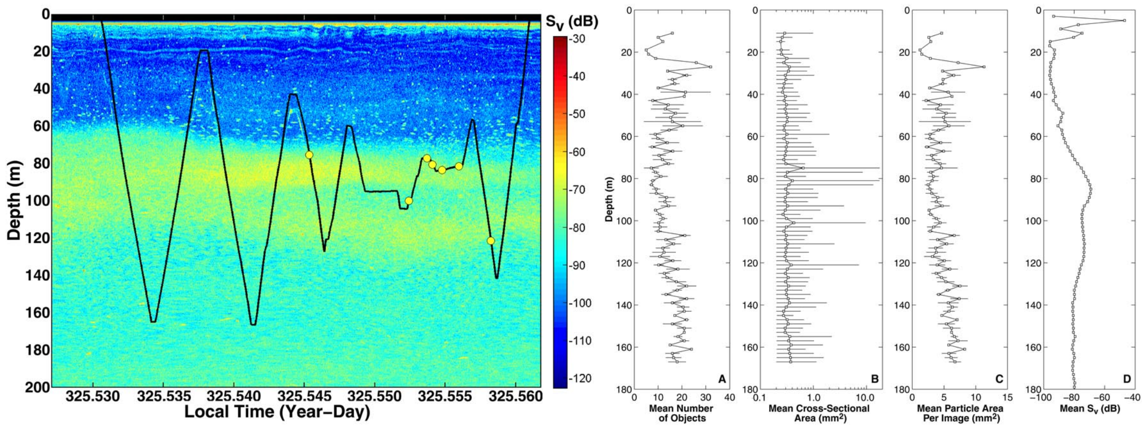

Figure 2. Left: trajectory of ZOOVIS overlaid on a 200 kHz echogram from Knight Inlet. The yellow circles indicate locations where ZOOVIS imaged euphausiids. The estimated density of euphausiids was consistent with mean measured scattering levels within the layer from 60-120m. Right: profiles of numbers of targets, cross-sectional area, mean particle area and mean volume scattering strength at 200kHz from the same ZOOVIS cast.

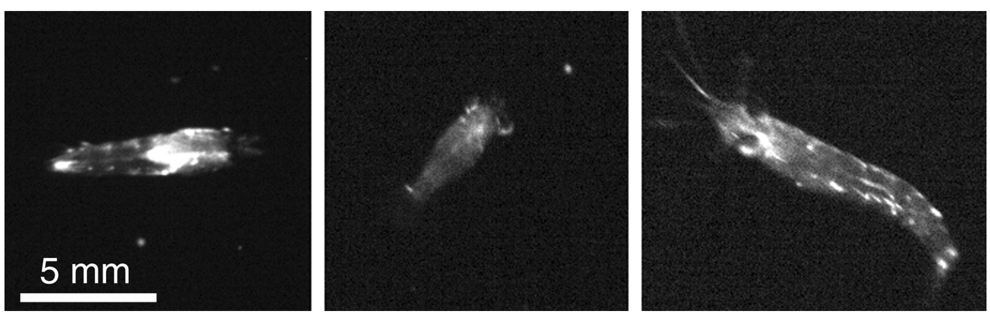

Figure 3. Example images of small euphausiids imaged by ZOOVIS in Knight Inlet. The images of these small ~8 mm long animals have been cropped from the full-field ZOOVIS images.

IMACT/APPLICATIONS

Understanding the relationship between observed scattering patterns and the underlying distributions of sound-scattering particles is a central problem in acoustical oceanography. The use of the camera system in Knight Inlet provides a means of verifying the composition of the sound scattering layers in the vicinity of the sill on spatial scales comparable to those of the acoustics.

Profiling instruments such as ZOOVIS have applications in a variety of regions that would prove problematic for towed instruments. The fjord system we examined was characterized by steep bathymetry and abrupt changes in depth that would pose a hazard for towed systems. Risks of fouling or colliding with fixed structures are also inherent problems when sampling around ice flows, from petroleum platforms, and around natural reefs. Providing that the depth of the bottom and locations of fouling structures are known, ZOOVIS can be safely operated in such areas. The ship’s echosounder provided a good estimate of the safe working depth beneath the vessel in Knight Inlet and permitted ZOOVIS to be deployed to within a few meters of the bottom on several occasions. The visible presence of ZOOVIS in the echosounder also assisted us in guiding the vehicle into the appropriate scattering layers.

The performance of ZOOVIS appears promising. Further analysis of the complete Knight Inlet dataset and intercomparisons with BIONESS casts and acoustic data will be required to assess potential biases of the system due to avoidance, however, the system yielded high-quality images of mesozooplankton and operated well in a fjord system. It appears to have met its design criteria for a system capable of quantifying the distributions and abundances of mesozooplankton in coastal waters. Comparisons with net data are ongoing. We have completed improvements in the frame (Fig. 4) utilizing a smaller and "stealthier" design that allows rapid adjustments to focus and illumination and are working on increasing network bandwidth (gigabit Ethernet). Ultimately, as digital camera technology evolves, improvements in the resolution of the camera will add capabilities to what is already a flexible instrument capable of quantitatively surveying a wide range of mesozooplankton in the coastal oceans.

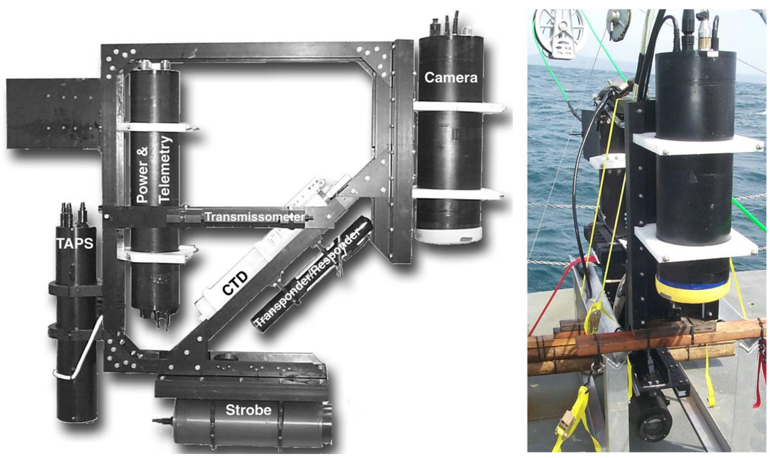

Figure 4. (Left) The new ZOOVIS frame constructed of anodized aluminum channel. The camera and strobe are mounted on moveable plates for rapid focus and illumination adjustments. A stabilizing fin is not shown. (Right) ZOOVIS on the stern of R/V Elakha off Newport Oregon.

RELATED PROJECTS

ZOOVIS was prepared for work off Newport, Oregon in April and May, 2002. This research was in collaboration with Dr. Timothy Cowles and Ms. Malinda Sutor (College of Oceanic and Atmospheric Sciences, Oregon State University) and was designed to utilize ZOOVIS to quantify the distributions and abundances of mesozooplankton within thin-layers. Weather conditions and power supply problems associated with using ZOOVIS from a small vessel (Fig. 4) prevented us from deploying the system, however, plans are try again in 2003 from a larger vessel. During November 2002, we will utilize the modified ZOOVIS system in Knight Inlet for the second cruise to examine acoustical scattering in the vicinity of the sill.

A collaboration between BAE Systems Inc. (N00014-00-D-0122) and LSU (N00014-01-1-0305) is developing scattering models based on high-resolution digitizations of zooplankton. Images from ZOOVIS contain sufficient detail to be digitized and modelled using this approach. We plan to begin with images of euphausiids collected in 2001.

PUBLICATIONS

Benfield, M.C., C.J. Schwehm, R.G. Fredericks, G. Squyres, S.F. Keenan, and M. Trevorrow. In Press. ZOOVIS: A high-resolution digital still camera system for measurement of fine-scale zooplankton distributions. In, P. Strutton, and L. Seuront (eds.) Scales in Aquatic Ecology: Measurement, Analysis and Simulation. CRC Press. Accepted for Publication June 2002.